

### Office of Nuclear Regulatory Research

### Development of the Extremely Low Probability of Rupture (xLPR) Assessment Tool

### Introduction

Title 10 of the Code of Federal Regulations Part 50, Appendix A, General Design Criteria (GDC) 4, "Environmental and Dynamic Effects Design Bases," requires that primary piping systems exhibit an extremely low probability of rupture in order to exclude dynamic effects associated with postulated pipe ruptures from the design basis. The deterministic leak-before-break (LBB) methodology, as described in the NRC Standard Review Plan (SRP) 3.6.3, was developed to meet this goal. In recent years, probabilistic analysis has matured to provide the flexibility to evaluate a wide variety of materials, degradation mechanisms, applications of mitigation techniques, and the influences of inspection. Hence, the NRC has initiated the development of a probabilistic assessment tool (xLPR) as an alternative to the deterministic evaluation criteria of the SRP. This poster provides an overview of the xLPR program, focusing on the collaborative structure used for model development and the current proof-of-concept pilot study.

### Motivation

- Systems approved for LBB have experienced degradation mechanisms such as primary stress corrosion cracking (PWSCC). The SRP was developed prior to the advent of this operating experience. xLPR will provide a probabilistic framework to address degradation mechanisms.
- In addition to modeling degradation mechanisms, xLPR models mitigation strategies (such as weld overlays) and the influence of inspection technology on pipe failure frequency.
- The xLPR program represents a cooperative process between the NRC and industry to develop a robust probabilistic software tool to improve design and regulatory decisionmaking.

### Objectives of NRC-Sponsored Research

- Develop a robust methodology for evaluating reactor coolant system piping rupture probabilities.
- Select appropriate, technically sound input data and models to produce best-estimate output results with quantified uncertainty.
- Develop a computational software tool that applies the input data and models and appropriately treats epistemic and aleatory uncertainties.
- Verify, validate, benchmark, and document the software tool to enable its use in support of design and regulatory decisions by both industry and the NRC.

## Low Alloy Steel Nozzle Alloy 182 Buttering Alloy 82/182 Butt Weld Stainless Steel Safe End Stainless Steel Field Weld Stainless Steel Field Weld

Nozzle geometry for xLPR pilot study

### Current Research Efforts-xLPR Pilot Study

- Intended to demonstrate the feasibility of the proposed NRC/industry cooperative process and the probabilistic framework.
- Develop an initial assessment tool for dissimilar metal pressurizer surge nozzle welds, accounting for weld residual stresses and PWSCC.
- Conduct a probabilistic assessment of surge nozzle dissimilar metal weld leakage and rupture.
- Provide order-of-magnitude estimates of piping rupture probabilities and identify areas requiring more focused attention in the long-term study.

### Pilot Study Task Group Structure

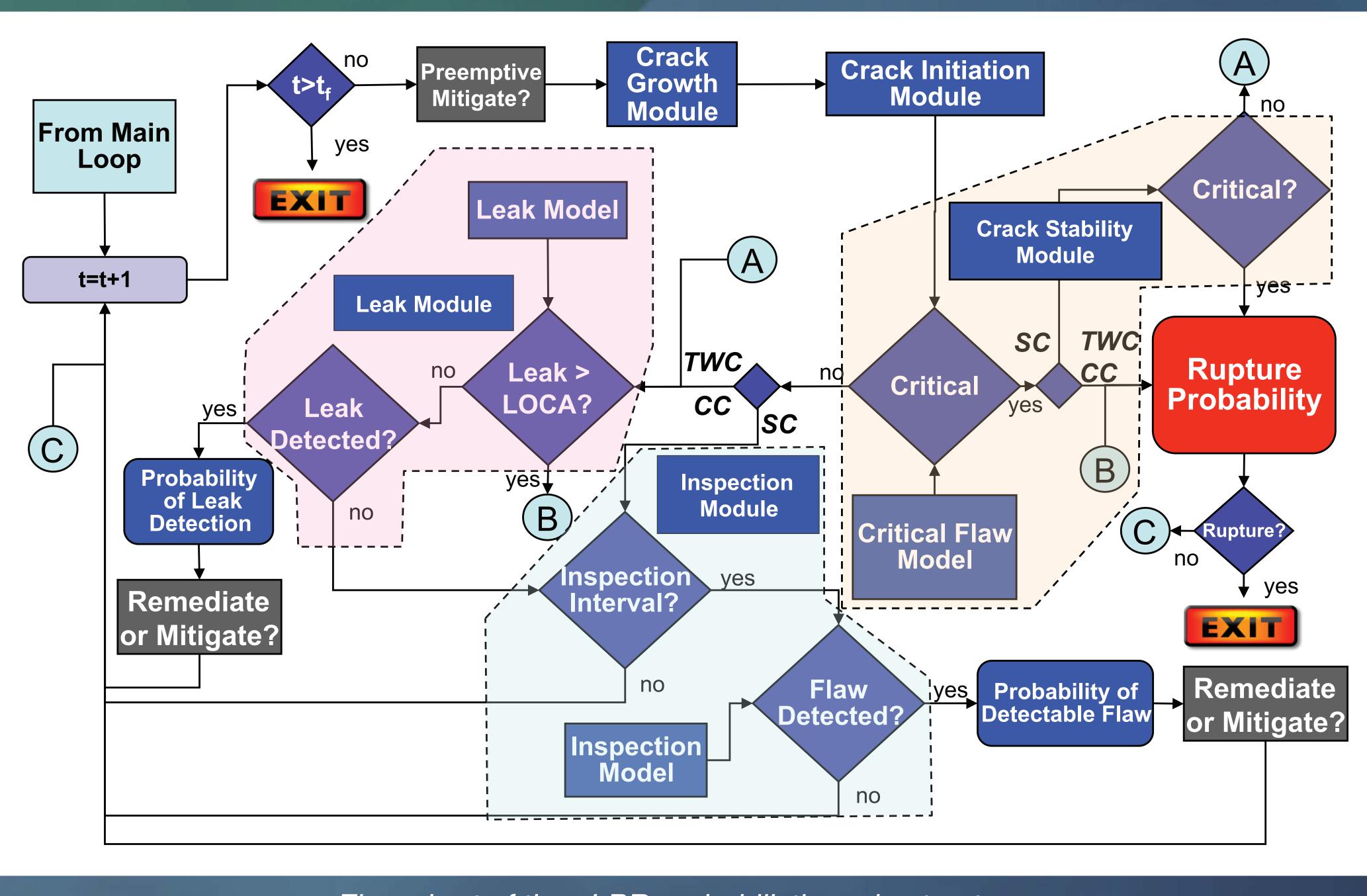
- Project Integration Board—Provide overall project direction (both for pilot and long term studies) and a mechanism for conflict resolution.
- Inputs—Determine and finalize inputs for xLPR, and develop model distribution for input parameters where possible.
- Models—Assess and develop models for xLPR.
- Computation—Develop a modular computation framework using open source (SIAM Group at Oak Ridge National Laboratory) and commercial software (GoldSim Group at Sandia National Laboratory), as well as coordinate the uncertainty analysis.
- Acceptance Criteria—Develop software quality assurance plan, recommend definition of "failure," recommend maximum tolerable "failure" frequency, and develop assessment metric for pilot study code.
- Review–Periodic review by an external review board.

# MRP Documents Industry Support Inputs Acceptance Regulations ASME Code Expert Judgment Path Forward for xLPR

Outline of the xLPR task group structure with task groups in blue.

### Deterministic Flow of xLPR Probabilistic Code

- xLPR code contains a time-based, deterministic kernel for calculation of physical behavior.
- Uncertainty propagation is controlled by sampling scheme and looping structure within code framework.



Flow chart of the xLPR probabilistic code structure.

## Material Properties Algorithmen Algorithm

Overview of xLPR inputs and outputs; with inputs (blue), probabilistic modeling (orange), and calculated rupture probability (red).

### Model Inputs and Outputs

- Inputs—Inputs include parameter distribution (for example material properties, load boundary conditions, and inspection frequency) and uncertainty quantification.
- Probabilistic Modeling—Probabilistic framework uses Monte Carlo, either simple random sampling or discrete sampling methods (binned analysis), or analytic method.
- Outputs—All data generated are saved for post-processing analyses, such as sensitivity studies or failure (loss of coolant accident - LOCA size) frequency as a function of time.

### xLPR Timeline

- Cooperative xLPR Research Program through NRC/EPRI MOU Addendum
- Pilot Study Alpha version completed 1st quarter 2010
- Pilot Study Final version complete—3rd quarter 2010
- xLPR complete–2012/2013
- Modular code complete–2016

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